

The Future of Jet Quenching

Peter Jacobs

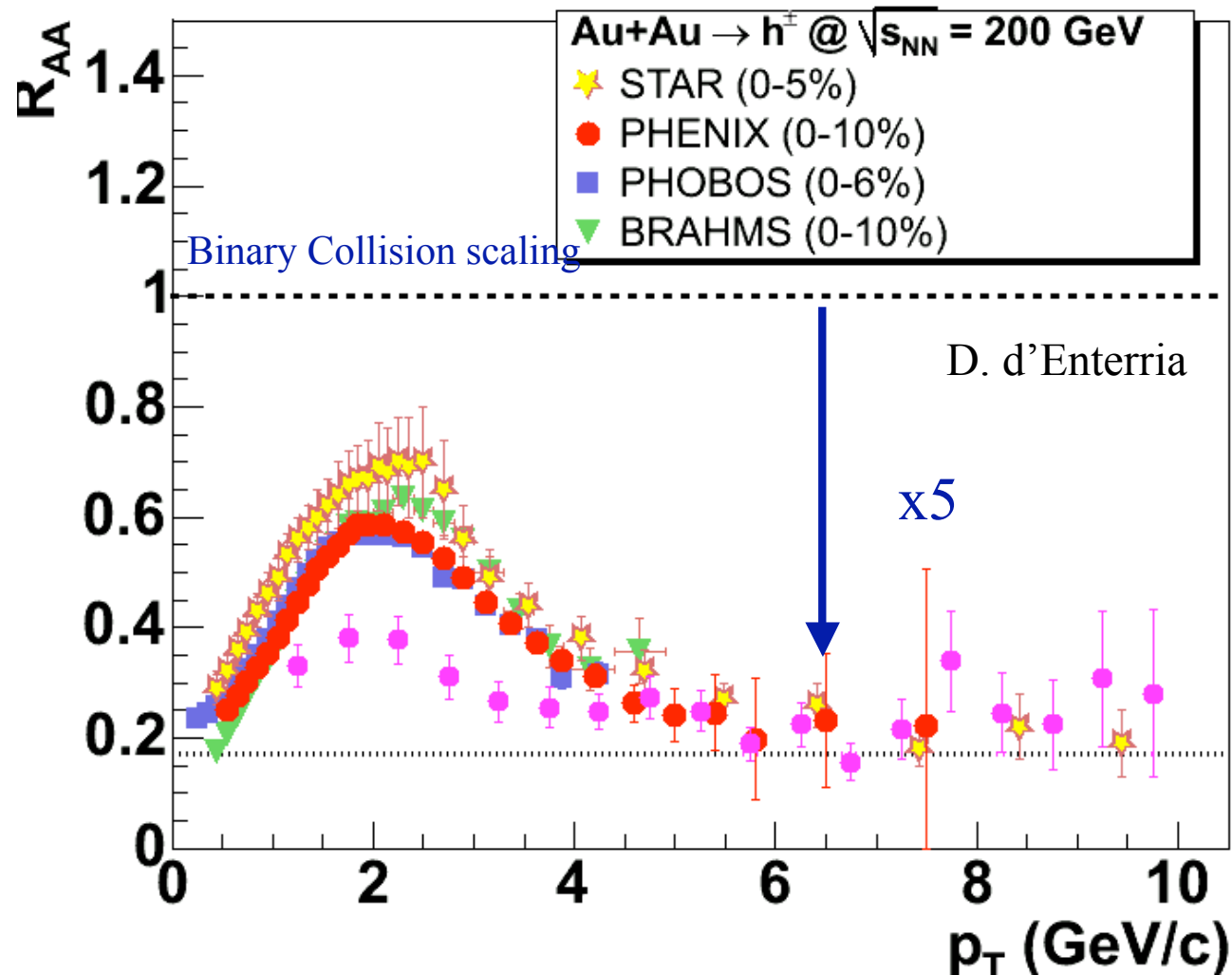


Very much a work in progress

Working definition of “Future”

$$\tau_i^{\text{sabbatical}} < \text{future} < \tau_{i+1}^{\text{sabbatical}} - 2[\text{years}]$$

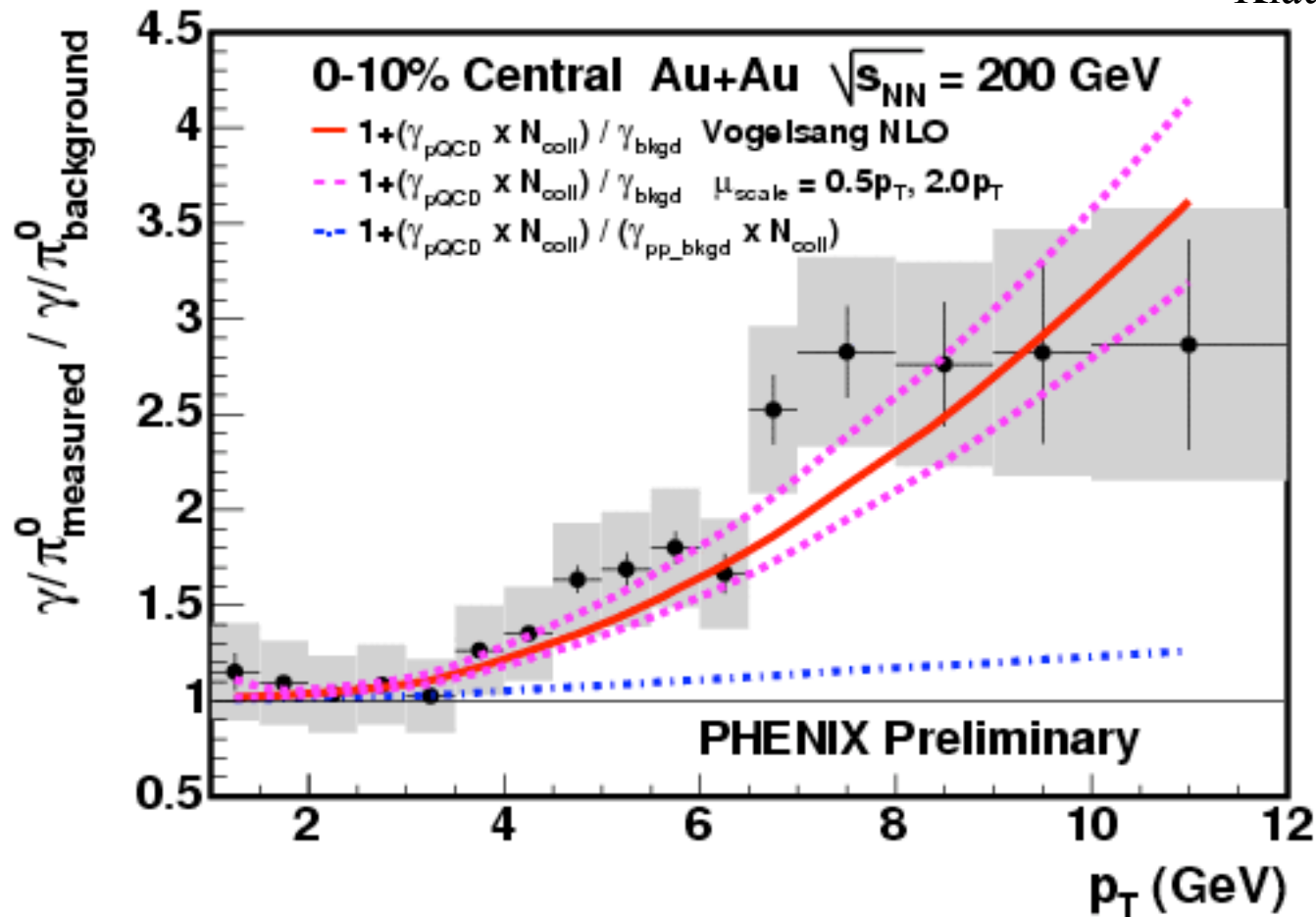
High p_T yields in central Au+Au are suppressed



Factor 5 suppression: huge effect!

Cross check: direct photons in Au+Au

Klaus Reygers



- Photons scale as binary collisions while π^0 are suppressed: consistent with energy loss picture
- but what does fragmentation component of photon yield do?

BDMPS energy loss governed by transport coefficient

$$\hat{q} = \frac{\langle \mu^2 \rangle}{\lambda} = c \varepsilon^{\frac{3}{4}}$$

Momentum broadening:

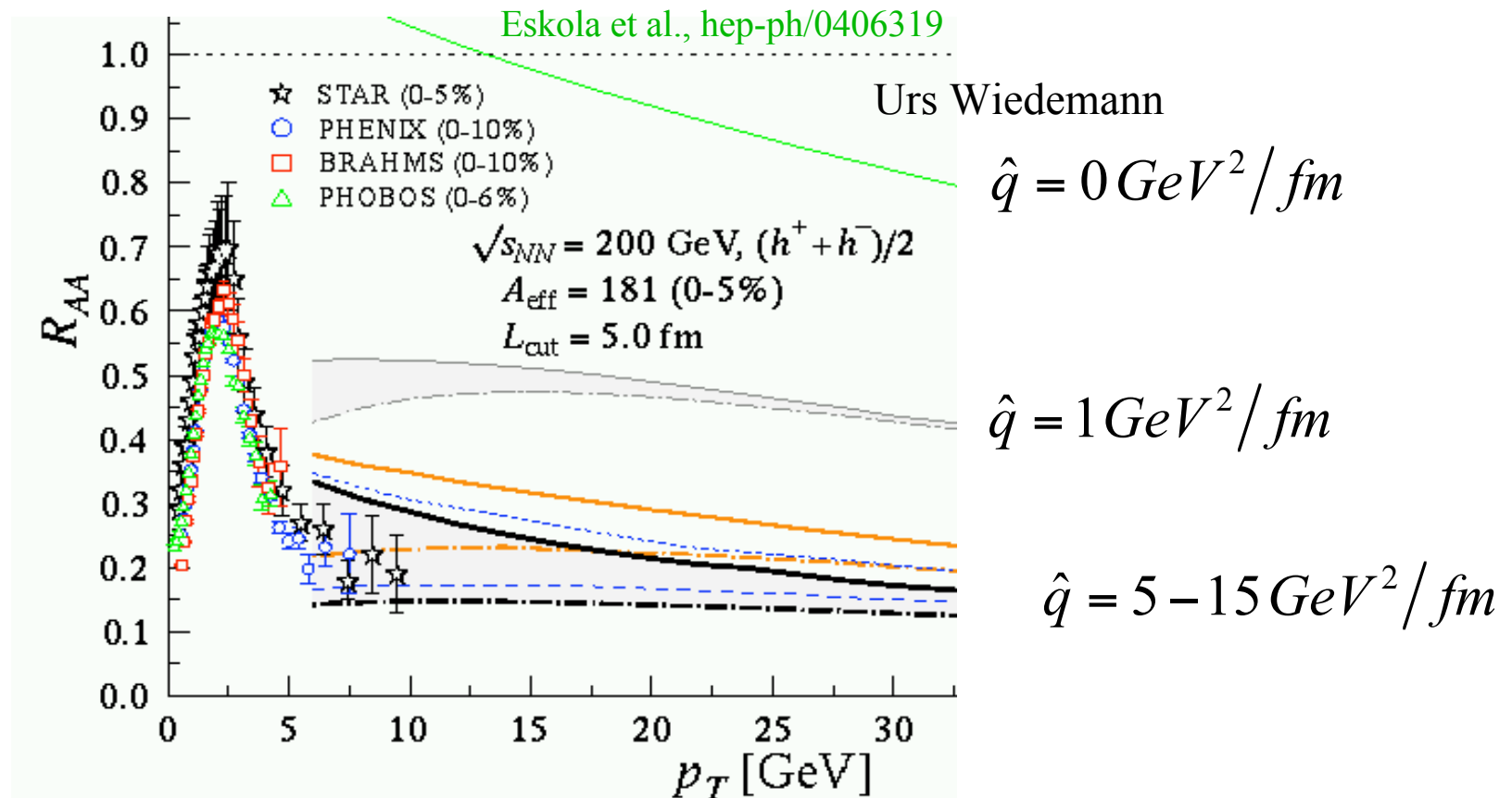
$$\langle k_T^2 \rangle \sim \hat{q} L_{medium}$$

Radiation spectrum cutoff:

$$\varpi_c = \frac{1}{2} \hat{q} L_{medium}^2$$

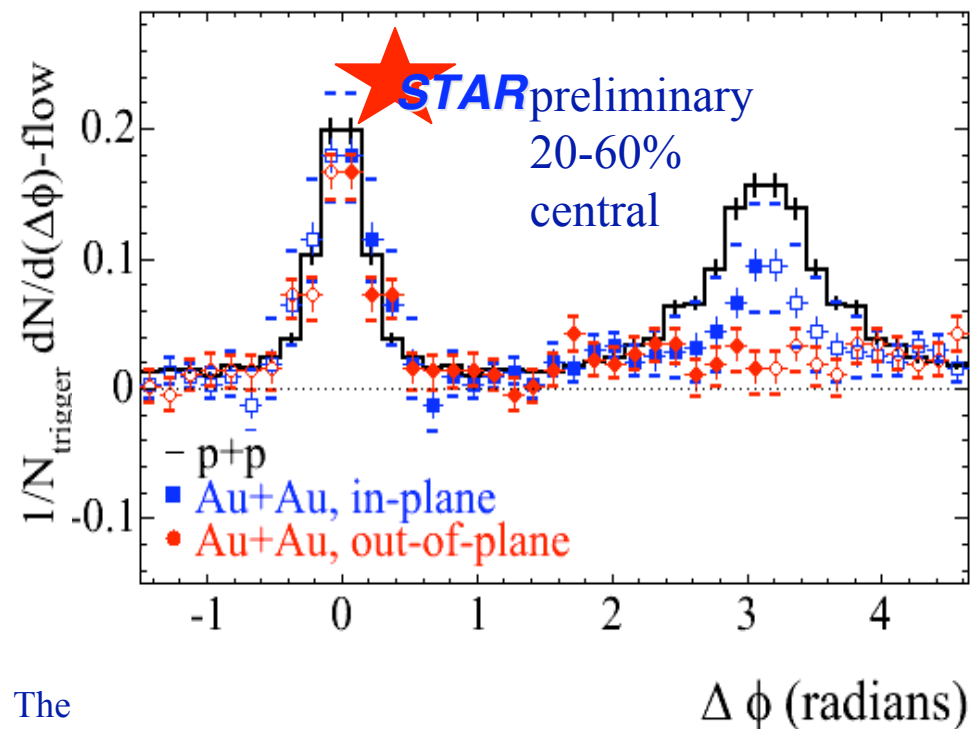
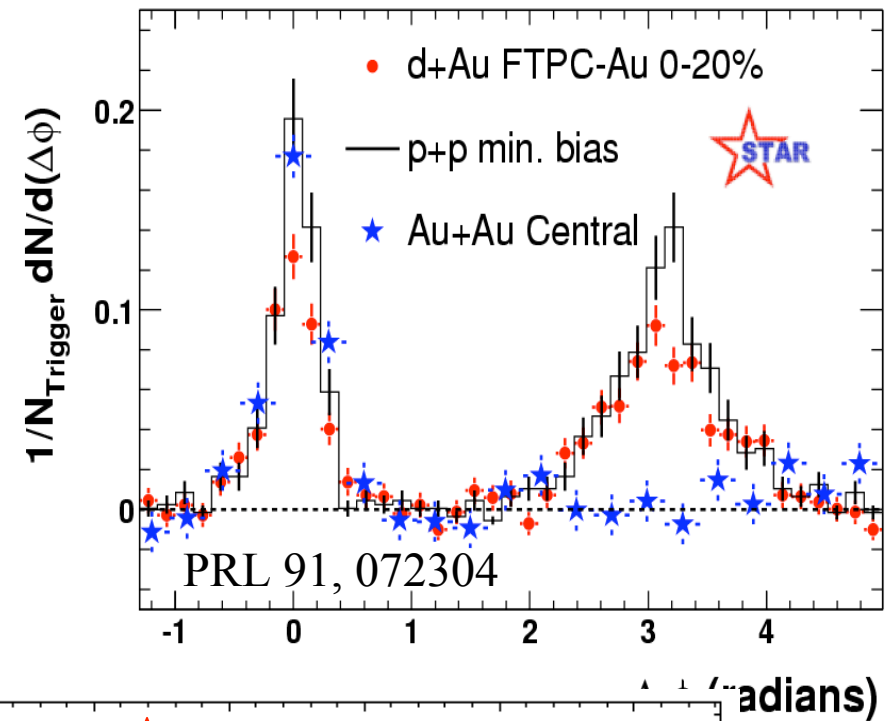
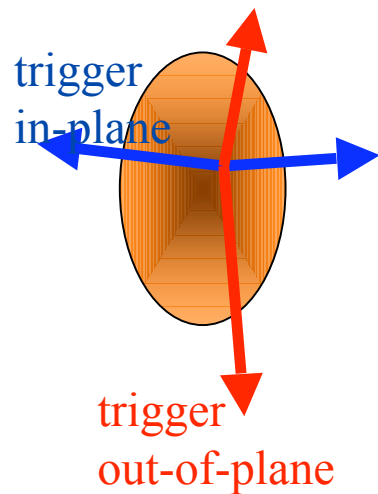
What do we learn from inclusive suppression?

Comparison to energy loss calculations: suppression requires initial density $> \sim 30$ times cold nuclear matter density



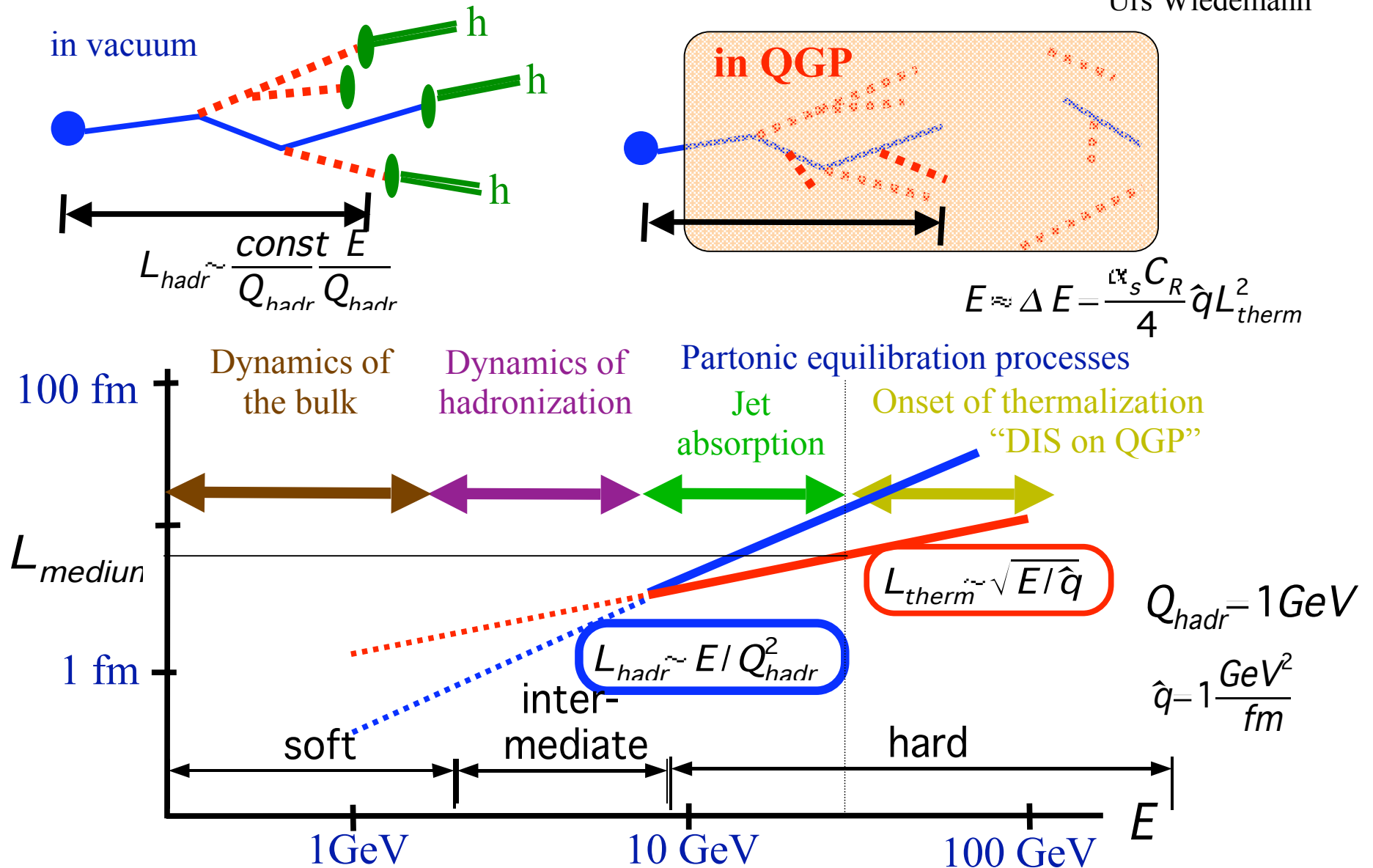
But suppression only supplies lower bound on density
(see also Drees et al., Loizedes et al.)

More discriminating: dihadron correlations



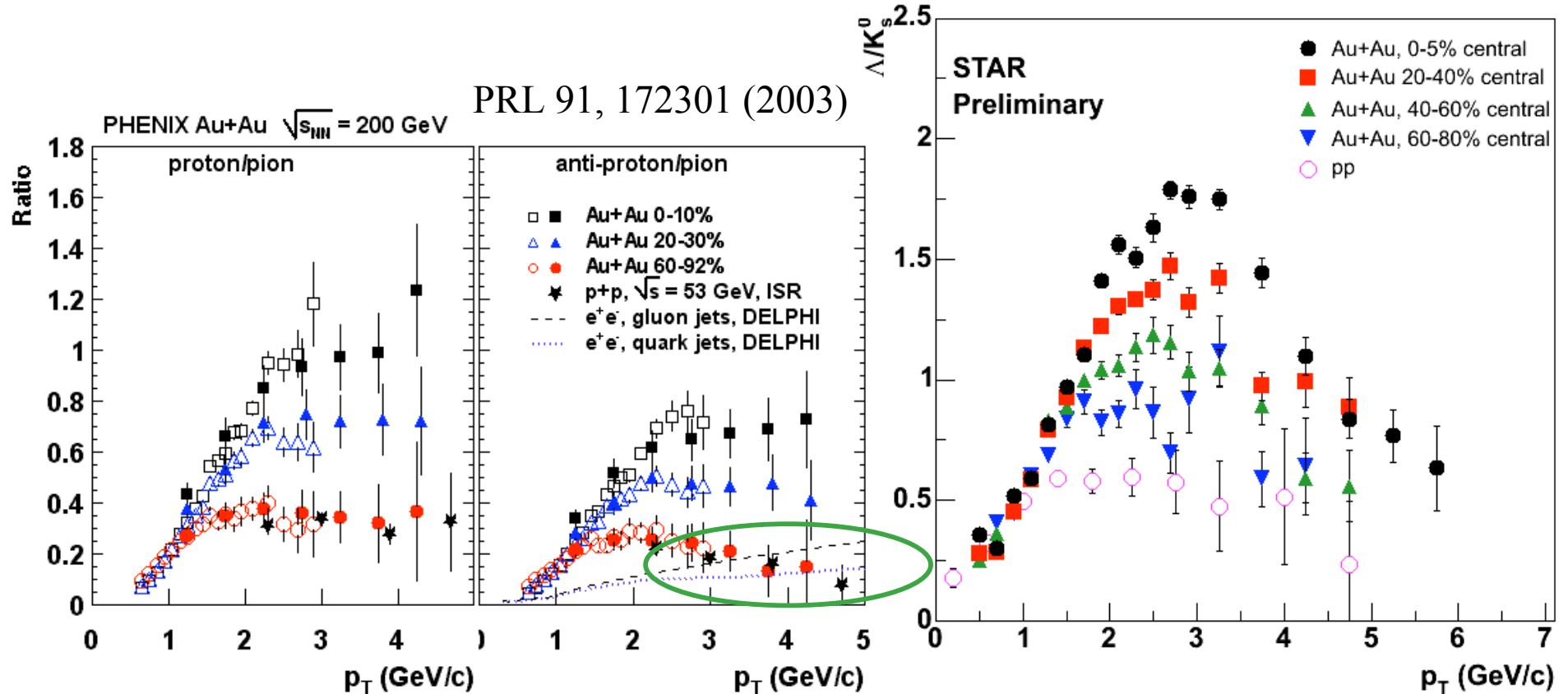
Hadronization versus Thermalization of Jets

Urs Wiedemann



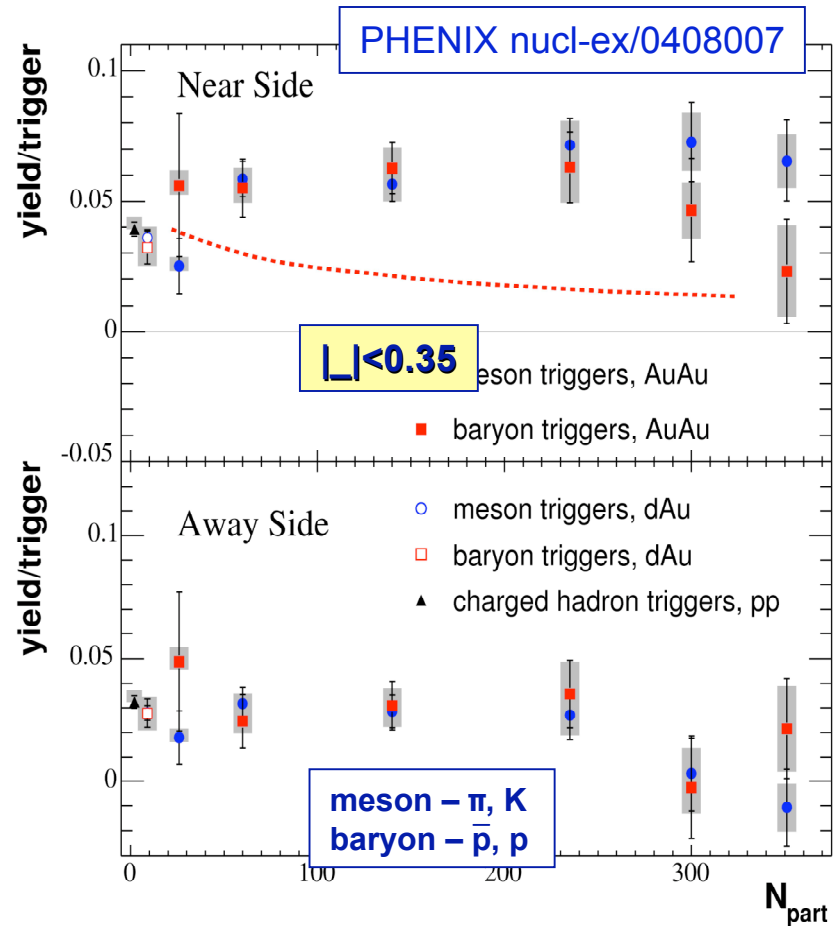
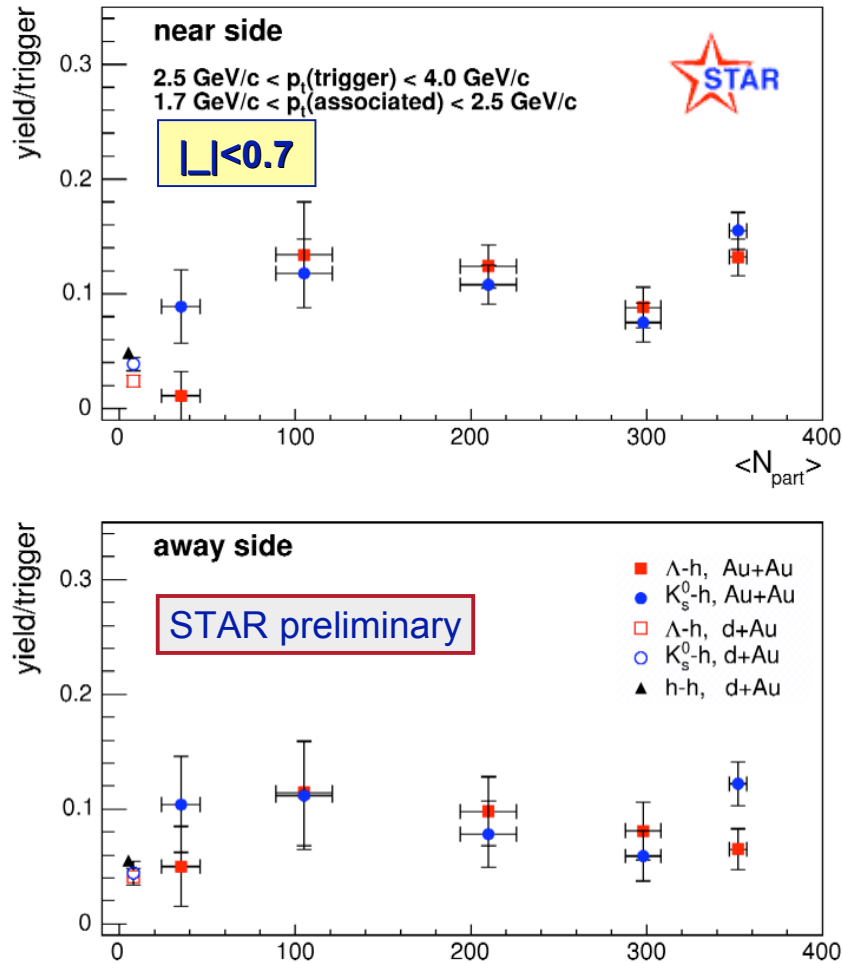
Heavy Ion Collisions: Intermediate p_T : expect unique interplay between probe and medium

Intermediate p_T



Central Au+Au: baryon/meson yields substantially in excess of expectations from jet fragmentation

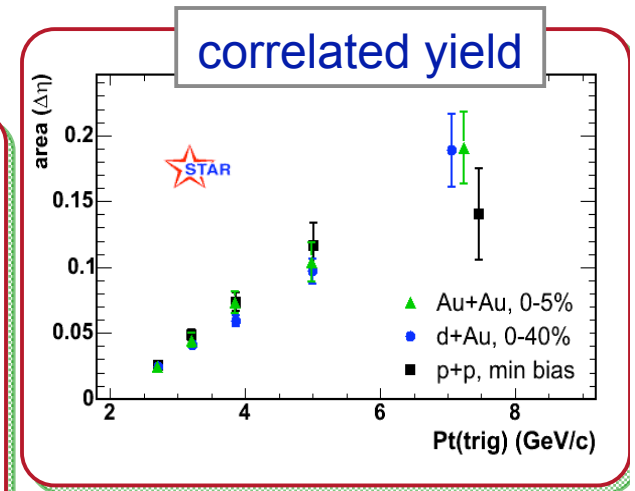
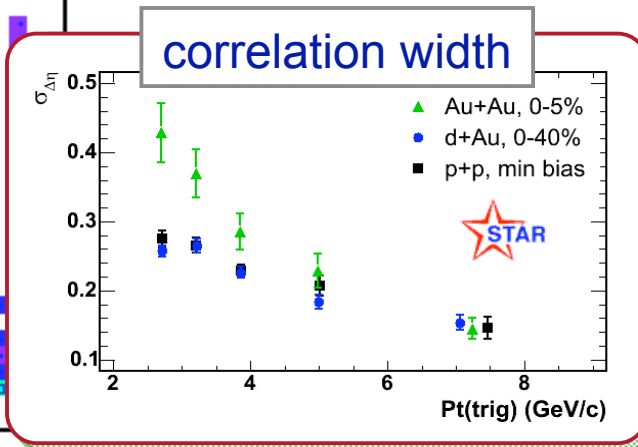
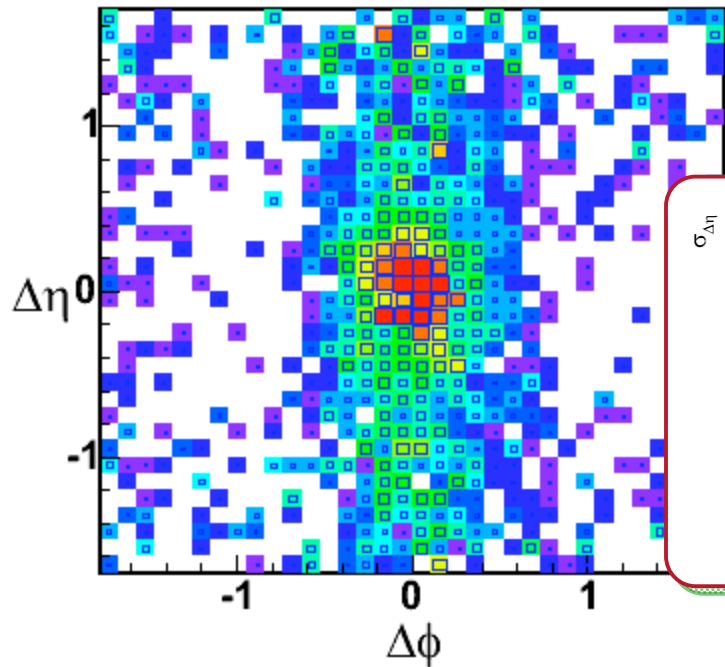
Meson vs baryon trigger: associated yields



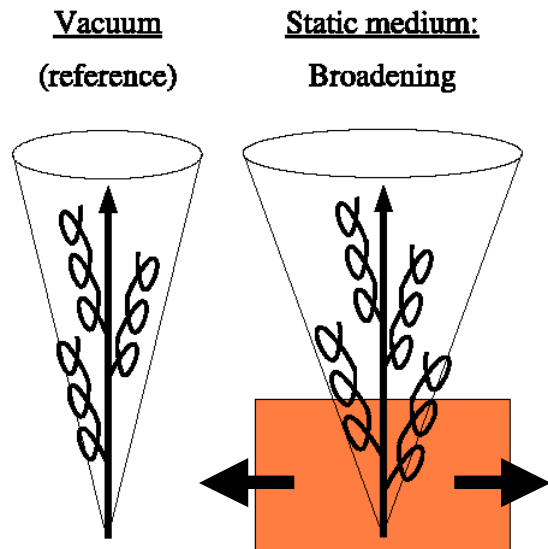
- Associated yields similar everywhere for meson and baryon triggers (perhaps weak dilution for baryons in central collisions)
- Dominance of jet-like production but widely differing suppression for baryons and mesons???

$\Delta\eta$ correlations

STAR/Dan Magestro



- Recombination effects? Coupling of radiation to flow medium?
- Long-range correlation: interplay of jet quenching and transverse radial flow?
- is picture of leading particle fragmentation and geometry biases wrong?



Armesto et al.

Associated soft hadrons

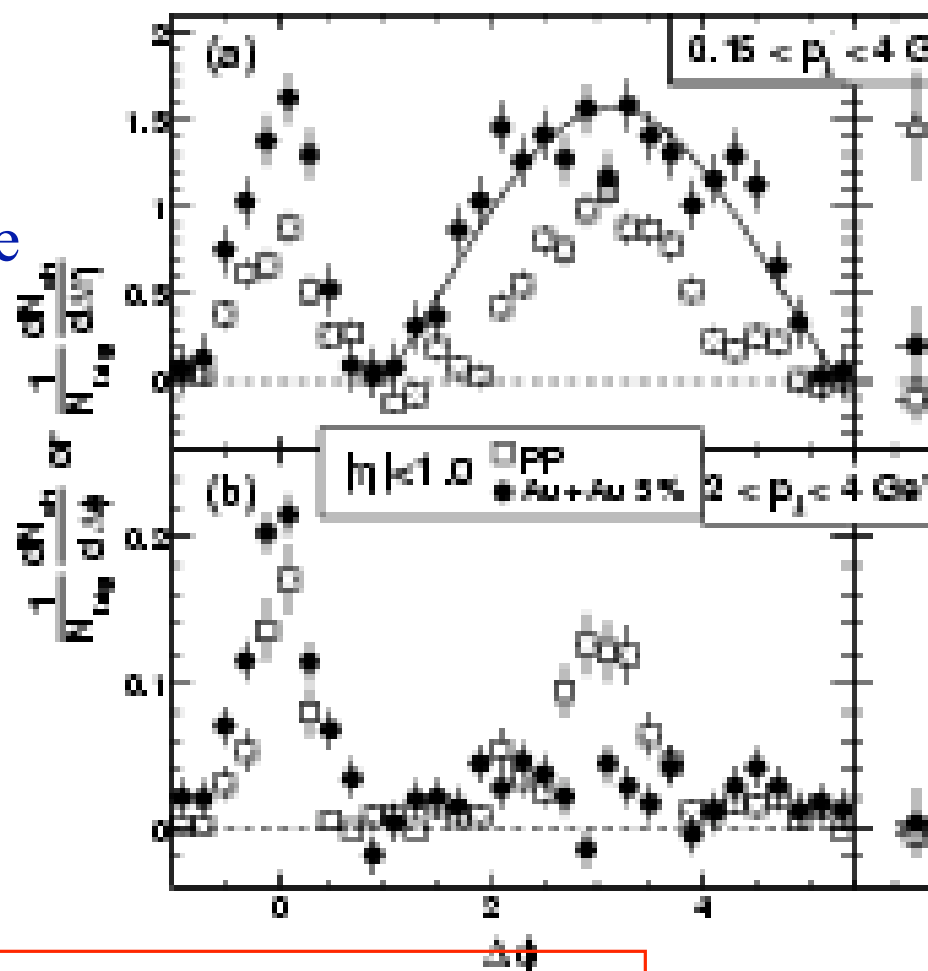
STAR/Fuqiang Wang

- Low p_T recoil broadened and softened relative to p+p

Qualitatively: consistent with simple momentum conservation

Quantitatively:

- signal/background $\sim 1/200$
- strong sensitivity to arbitrary choices for bkgd subtraction
- non-jet sources of correlations



IMHO: significant open interpretational issues;
still far from “jet reconstruction”

Summary thus far

- Strong modification of jet fragmentation in high energy nuclear collisions exists
- Broad agreement with pQCD + energy loss via induced bremsstrahlung
- Intermediate p_T seems to play a special role: interface between hard and soft processes

Some lessons

1. The most abundant hard probes are the most interesting hard probes because:

- they are hard probes: created early, sensitive to hot and dense phase, survive system evolution
- they are abundant: can be tested multiple ways and characterized in detail

2. Studying modification of jet fragmentation by the medium is as interesting and fundamental as applying modification of jet fragmentation as a probe of the medium.

(jet quenching haiku in preparation)

Open issues

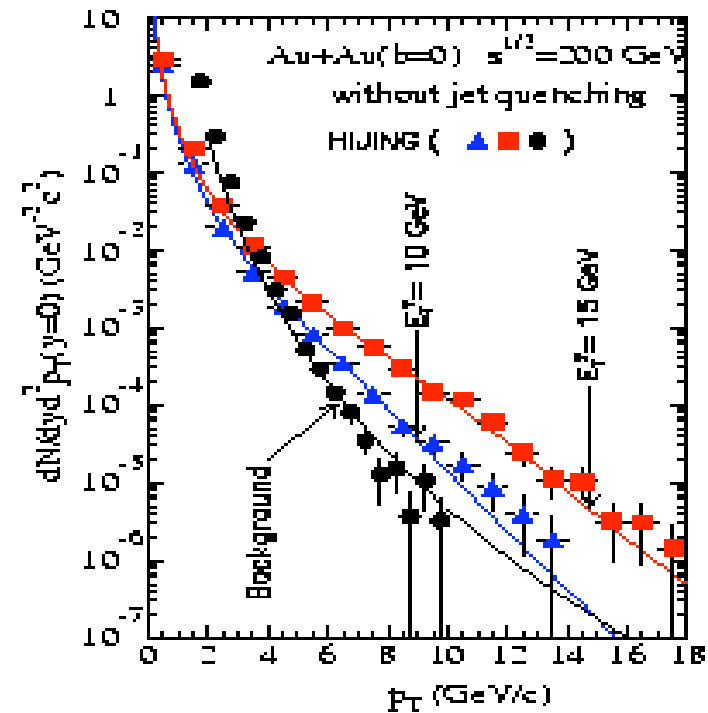
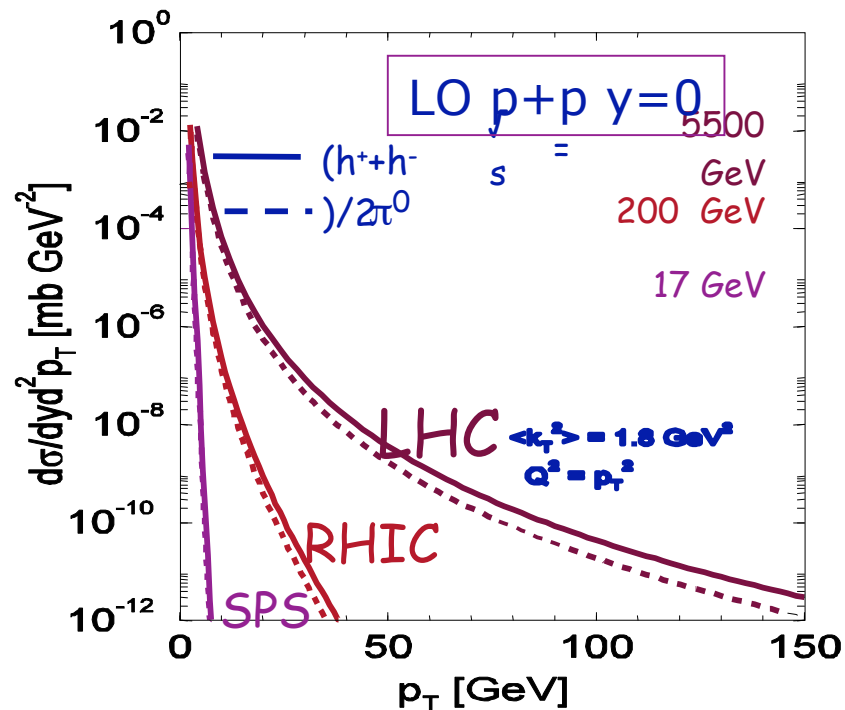
Evidence for jet quenching is thus far only indirect

To make progress we need to probe our understanding in various ways:

- observe the induced radiation directly
- observe color-charge dependence (gluon, light quark, heavy quark)
- study interactions of radiation with medium
- study processes driving system towards equilibration; can we use p_T scale as dial to control degree of equilibration?

Study of jet physics in nuclear collisions promises to yield more than just a value for q_{hat} !

RHIC II and LHC



Some available tools

1. Reduce geometric and fragmentation biases:
 - γ +jet (problematic at LHC due to large QCD backgrounds),
Z+jet
 - quasi-full jet reconstruction
2. Heavy vs light quark:
 - “dead-cone” effect not as simple as initially proposed
 - Wiedemann et al.: light meson vs D vs B suppression probes both mass effect and color charge dependence
3. 3-jet events: isolate color charge dependence?
4. Correlations of very hard hadrons: pQCD-treatable?

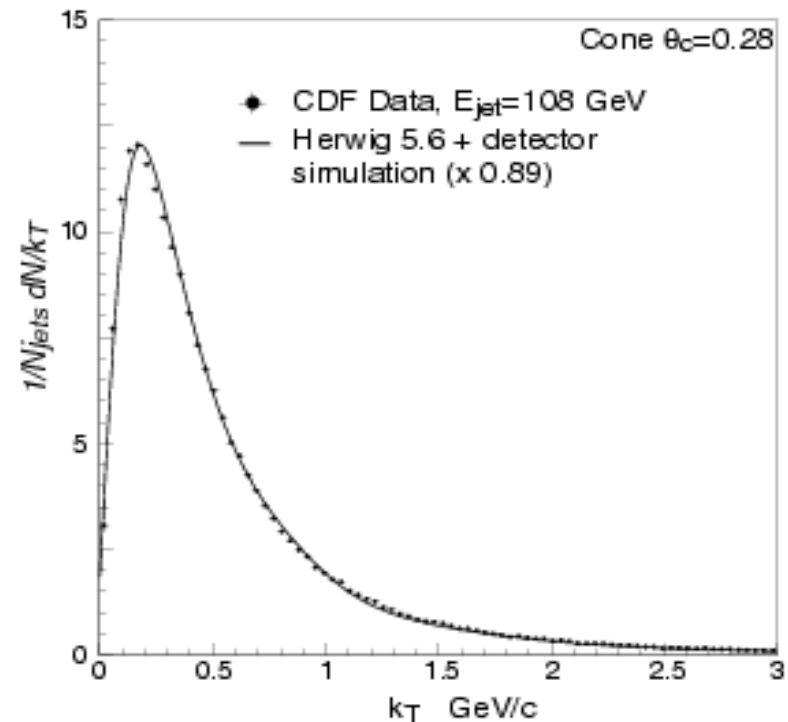
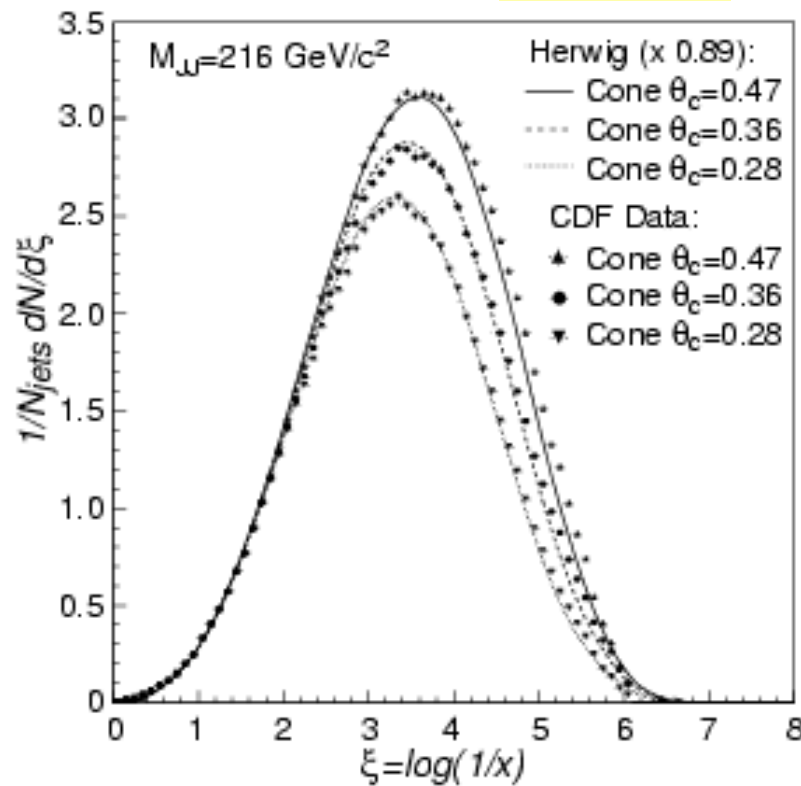
5, 6, 7,

CDF: hadron distributions in jets

$$\xi = \log\left(\frac{1}{x}\right)$$

$$x = \frac{p}{E_{jet}}$$

$$k_T$$



Herwig: shapes right in detail over broad momentum range,
 overestimates multiplicity by ~11%

Fragmentation in the Modified Leading Log Approximation (MLLA)

- Resummed pQCD: sum terms like $\alpha_s^n \log^{2n}(E_{jet})$ to all orders
- only hadronization assumption: local parton-hadron duality
- one model parameter: cutoff momentum $Q_{eff} \sim \Lambda_{QCD} \sim 250 \text{ MeV}$
- parameters are measurable, assumptions testable (CDF)

Analytic expression for momentum distribution in gluon jets within cone $\theta < \theta_c$:

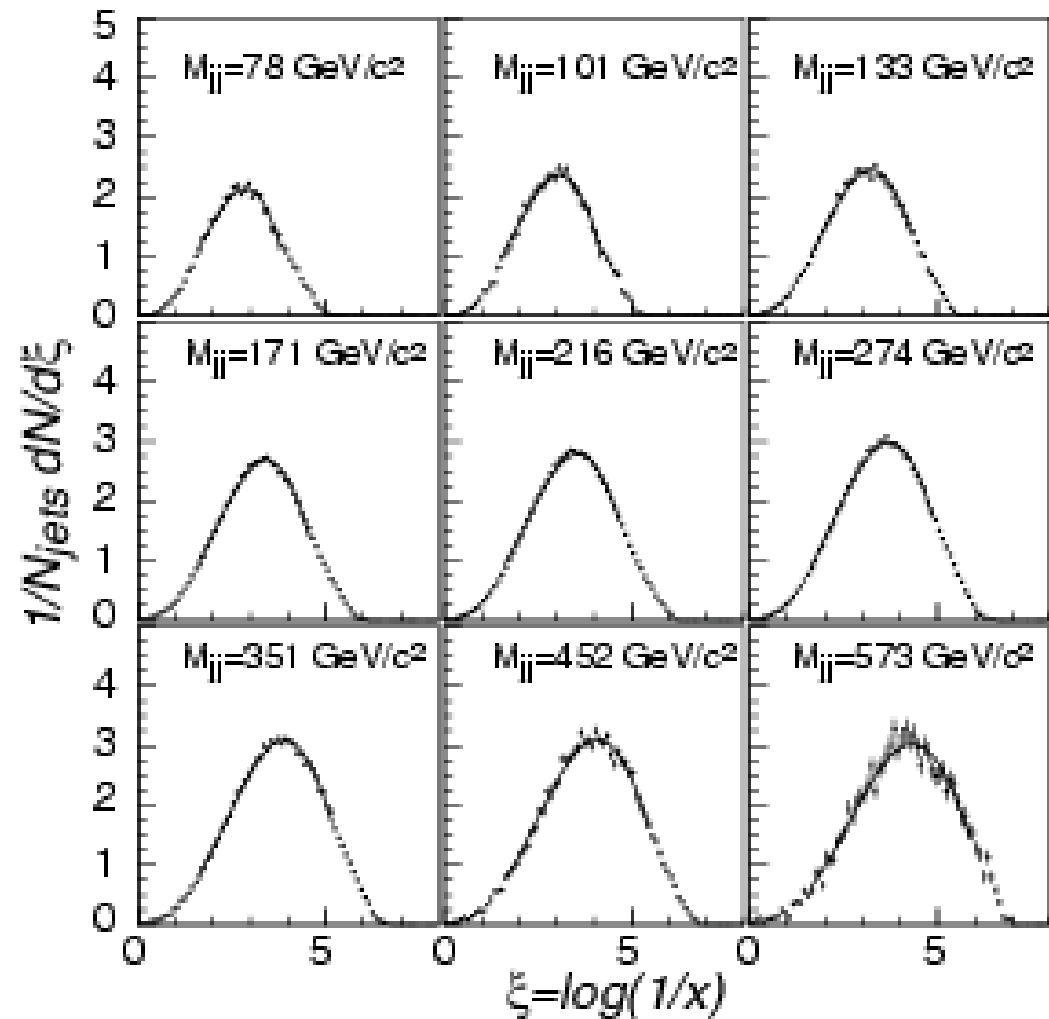
$$\frac{dN_{partons}^{g-jet}}{d\xi} = \frac{4n_c}{b} \Gamma(B) \int_{-\pi/2}^{\pi/2} \frac{d\tau}{\pi} e^{-B\alpha} \times \left\{ \frac{\cosh \alpha + (1 - 2\zeta) \sinh \alpha}{\frac{4n_c}{b} Y \frac{\alpha}{\sinh \alpha}} \right\}^{B/2} \times I_B \left(\sqrt{\frac{4n_c}{b} Y \frac{\alpha}{\sinh \alpha} (\cosh \alpha + (1 - 2\zeta) \sinh \alpha)} \right),$$

$$x = \frac{p}{E_{jet}}$$

$$\xi = \log\left(\frac{1}{x}\right)$$

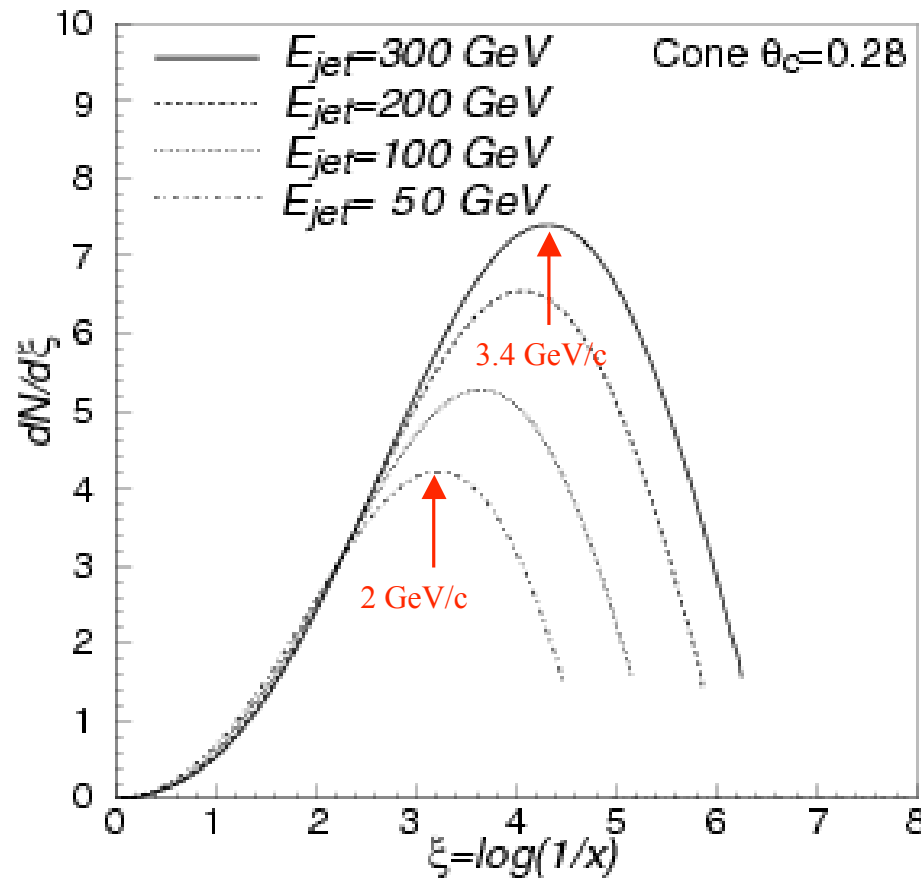
$$\text{Scaling variable: } Y = \log\left(\frac{E_{Jet} \sin \vartheta_c}{Q_{eff}}\right)$$

MLLA vs CDF data



- Agreement is superb over wide range of fragment momentum and dijet mass
 - MLLA scaling excellent
- ⇒ major success for pQCD!

MLLA: evolution with jet energy



$$x = \frac{p}{E_{jet}}$$

$$\xi = \log\left(\frac{1}{x}\right)$$

- Peak at $\xi = 3-4$ ($x=0.02-0.05$) $\Rightarrow p_T \sim 2-3$ GeV/c
- Most hadrons are soft \sim few GeV even for the hardest jets!

Can medium-induced modification of fragmentation be studied on the same fundamental level of pQCD?

I leave it to others to critique current energy loss theory

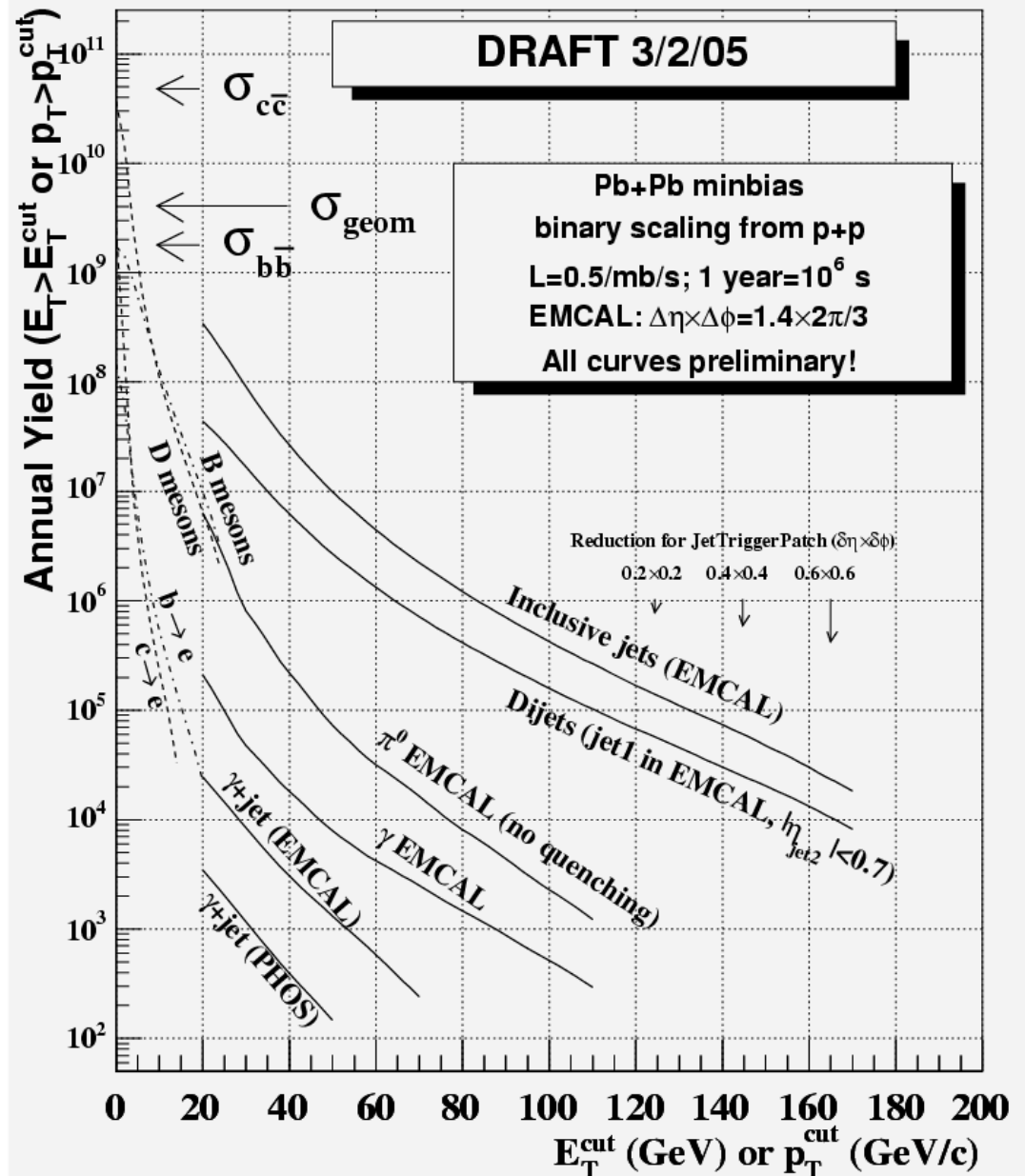
Requirements on experimental side:

- Broad reach in E_{jet} to be sensitive to evolution $\sim \log(E_{\text{jet}})$
- fragmentation measurements:
 - CDF jet energy resolution $\sim 10\%$
 - tracking over wide momentum range (500 MeV \rightarrow >50 GeV)
- sensitivity to new physics at interface of hard and soft momentum scales (“intermediate p_T ” $\sim 2\text{-}5$ GeV) \Rightarrow PID
- new element in ion collisions: gluon saturation:
 - extended scaling region ~ 10 GeV at LHC??
 - influence at intermediate p_T ?

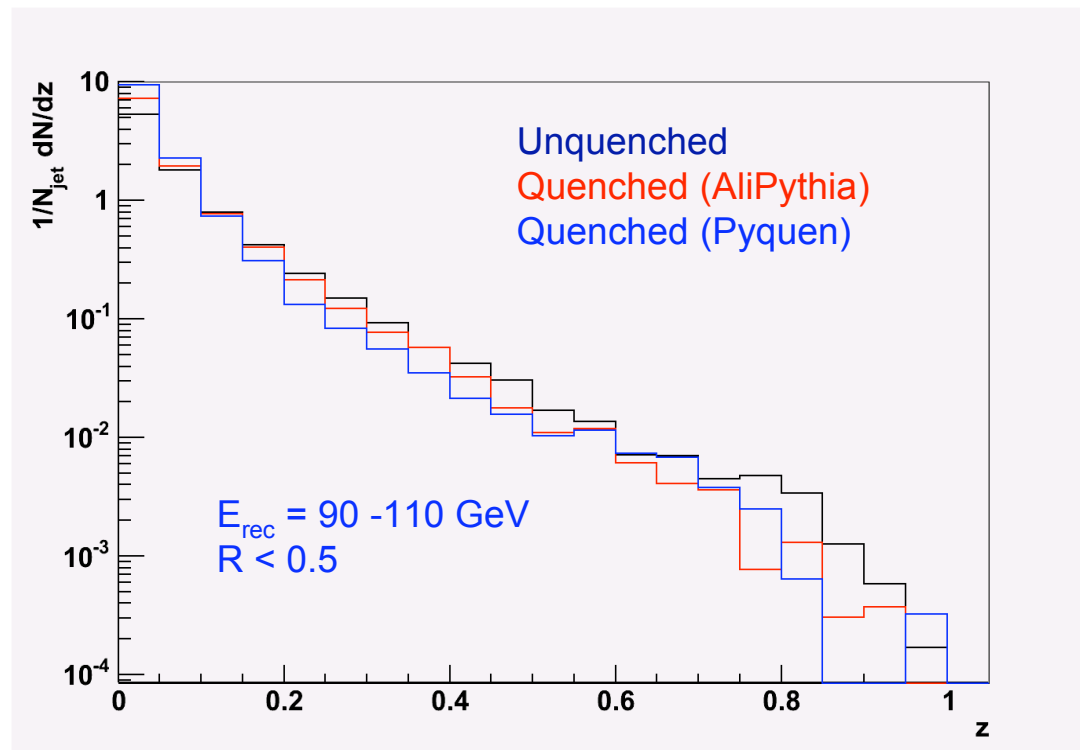
Hard Process rates in ALICE

ALICE+EMCAL is
in LHC heavy ion jet
game without
apology!

Integrated hard process rates in ALICE



Direct measurement of fragmentation function?

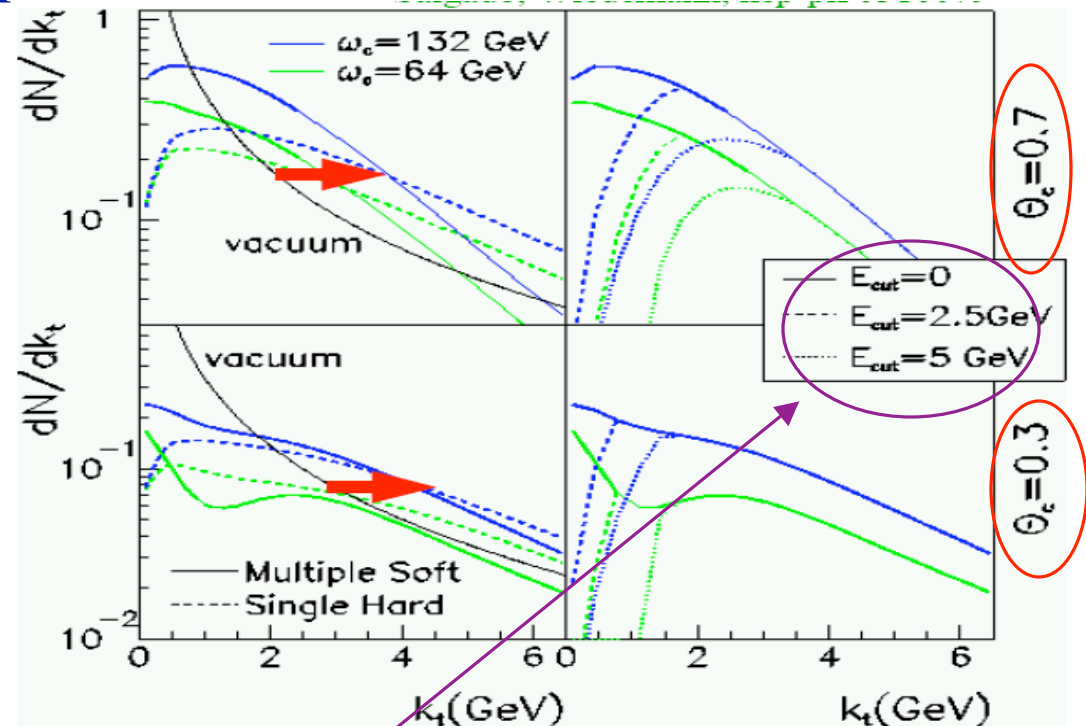
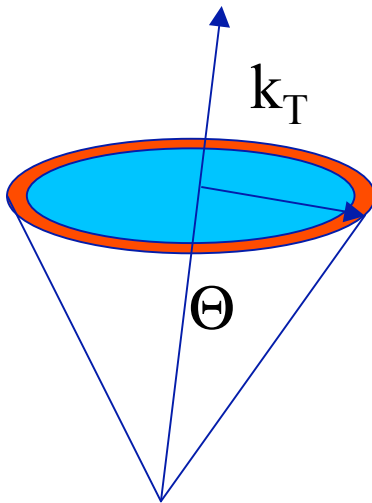


Normalizing to actual partonic energy is difficult:
finite cone biases reduce sensitivity

Will know much more about backgrounds and
broadening with first LHC data

Observables \sim independent of full jet reconstruction

e.g. Transverse heating of jets in finite cone
Salgado + Wiedemann, hep-ph/0310079



- Trivial geometry: for finite cone angle, large k_T only for large gluon energy
- Signal emerges at intermediate p_T

Conclusions